

# Performance Characteristics of Quasi-Single Longitudinal-Mode Fabry-Perot Lasers

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**Abstract**—The performance characteristics of a quasi-single longitudinal-mode Fabry-Perot (FP) laser manufactured by longitudinal modal perturbation of a conventional FP laser are presented. A  $K$  factor of 0.67 ns, a linewidth below 41 MHz and a chirped spectral width (20 dB down full width) of 0.56 nm are reported. Such performances and the low cost involved with the manufacturing process should result in more widespread use of such single-mode lasers in various application areas.

## I. INTRODUCTION

**C**OUPLED-CAVITY lasers were an early cavity design used to obtain single longitudinal mode behavior from a monolithic device [1]. They suffered, however, from poor single-mode stability under large signal current modulation. Today, the majority of monolithic single-mode semiconductor lasers are of the distributed feedback (DFB) type or variations of the same. The DFB laser has set many impressive records including modulation bandwidth [2], linewidth [3] and temperature sensitivity [4]; the last two characteristics having been obtained with variations on the basic DFB laser structure. Although this laser structure has found many areas of application outside its original telecommunications field, its cost of production has prevented its widespread exploitation. This is primarily due to the high costs involved with the grating layer fabrication.

In the current letter, performance results are reported for a quasi-single-mode laser in which the mode selectivity has been produced by introducing "slots" [5] at precise longitudinal positions along the laser length. Unlike other methods that modulate the gain or loss at defined locations [6]–[7], the present method loads the cavity refractive index by introducing etch slots at desired cavity locations. By etching a slot perpendicular to the laser longitudinal axis the "local" effective refractive index experienced by certain guided modes is reduced. The set of modes which are influenced are crucially dependent on the position of the slot relative to the nearest laser facet. The modes that satisfy the lasing condition for the coupled cavity are reinforced and so have a lower threshold gain and reach threshold first. By introducing additional slots at precise fractional positions relative to the cavity length, almost

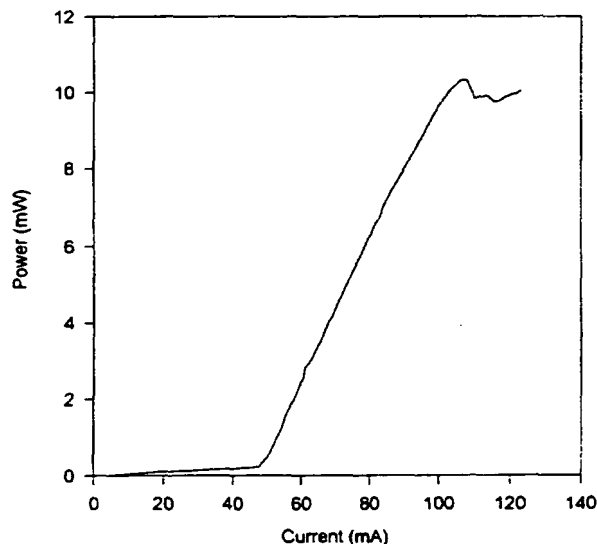


Fig. 1. Light-current characteristic of the quasi-single-mode laser @ 20 °C.

any desired lasing spectrum can be carved from the original Fabry-Perot spectrum.

Although the performances reported here fall well short of the record performances of conventional DFB lasers having  $e$ -beam defined gratings, and derivatives of this basic structure, they are usable for many applications and are obtained at a fraction of the normal processing cost.

## II. RESULTS AND DISCUSSION

A description of the device structure, the choice of slot locations along the cavity and the precise etching/processing steps involved in the laser fabrication can be found in a previous publication [5]. The laser characterized in the present report has a cavity length of 400  $\mu\text{m}$ , to within 1  $\mu\text{m}$ . The light-current ( $L$ - $I$ ) characteristic for this device at 20 °C is presented in Fig. 1. The threshold current is 48 mA and represents an increase of 6 mA from the nonperturbed FP cavity case.

The  $L$ - $I$  curve is well behaved for biases up to 85 mA and has an external quantum efficiency of 0.2 mW/mA per facet, approximately. For higher biases the power saturates and actually decreases as the laser under goes multiple mode jumps to longer wavelengths, each jump being eight standard FP cavity modes apart [5]. At present this behavior limits the maximum operating output power of the device. By inserting "slots" at 1/16, 1/32, etc. of the cavity length the power

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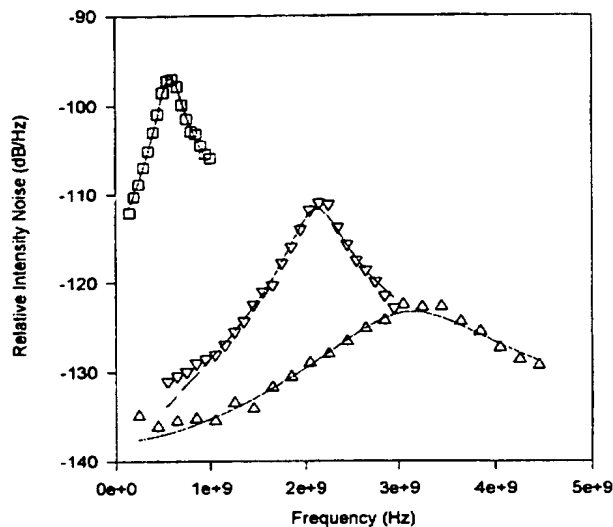


Fig. 2. Relative Intensity Noise (RIN) measurements at 50 ( $\square$ ), 70 ( $\nabla$ ), and 100 ( $\triangle$ ) mA for the quasi-single-mode laser. The solid line is the corresponding curve fitted results.

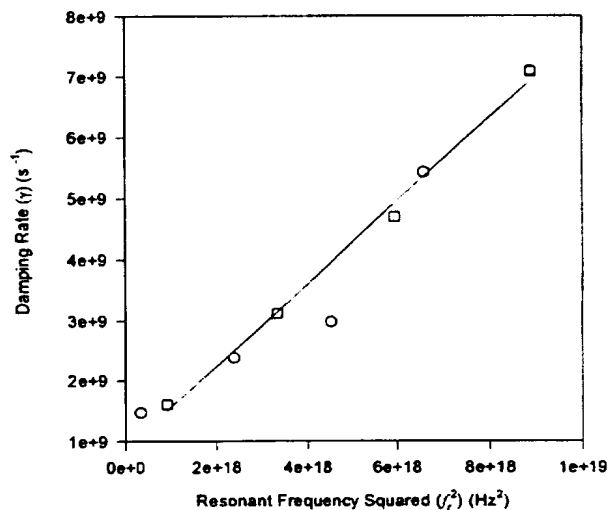


Fig. 3. Damping rate ( $\gamma$ ) versus resonant frequency ( $f_r^2$ ) squared.  $K = 0.67$  ns for the standard FP laser ( $\square$ ) and  $0.68$  ns for the quasi-single-mode device ( $\circ$ ).

stability, in addition to many other characteristics of the laser, will be improved [5]. Devices containing these additional slots are currently under study and will be the subject of a future publication.

Relative Intensity Noise (RIN) measurements as a function of bias current (Fig. 2) allow the damping rate ( $\gamma$ ) and the relaxation oscillation frequency ( $f_r$ ) to be determined for the quasi-single-mode laser under study and, for comparison, a standard FP of similar length from the same laser bar which is without "slots." Fig. 3 is a plot of  $\gamma$  versus  $f_r^2$  for both devices from whose slopes the Olshansky  $K$  factor are readily obtainable. For the quasi-single-mode device  $K = 0.68$  ns while the standard FP has  $K = 0.67$  ns, using a least squares fit to the measurement data. Although these  $K$  values are quite large and represent a maximum modulation bandwidth of only 4.2 GHz for the present ridge waveguide structure,

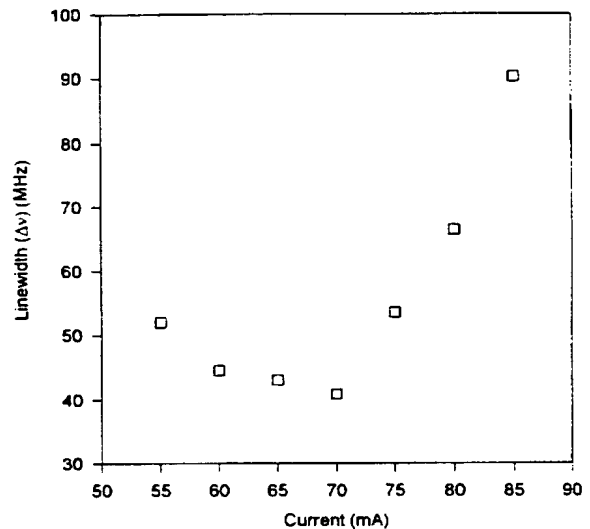


Fig. 4. Self-homodyne linewidth ( $\Delta\nu$ ) versus laser bias. A minimum linewidth of 40.7 MHz is obtained at a bias of 70 mA.

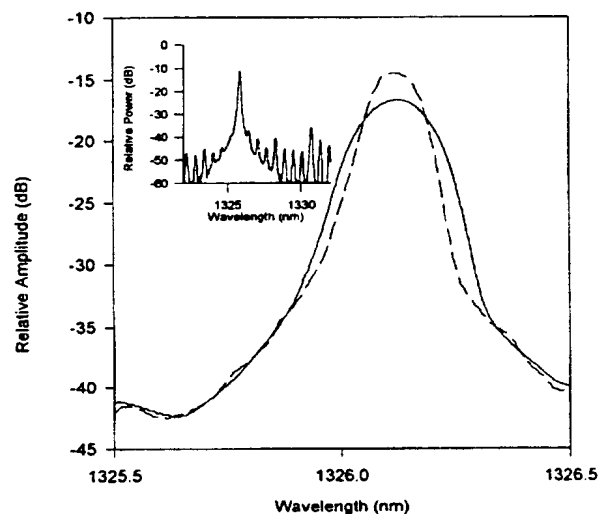


Fig. 5. Spectrum of the main lasing mode under 100-ps pulses, 36-mA current modulation superimposed on a bias of 60 mA. Inset: a wider span of the laser spectrum about the main mode under modulation.

the values are comparable for both devices and emphasise that the processing step used to define the "slots" does not compromise the device's frequency response. An improved lateral confining structure, a decreased cavity length and the use of a quantum-well active region are expected to decrease  $K$ .

Many potential application areas of single-mode semiconductor lasers require good single-mode spectral purity. Using the self-homodyne linewidth measurement technique, the 3-dB linewidth ( $\Delta\nu$ ) has been noted as a function of bias current (Fig. 4) for this quasi-single-mode device. The linewidth initially decreases from 52 MHz to below 41 MHz, in accordance with the inverse relation between linewidth and output power. Beyond this the linewidth rebroadens due to SMSR degradation (see Fig. 2, reference 5). Although these values are far from the current state of the art for monolithic single-mode lasers [3] they compare very favorably with the linewidth

values observed for DFB lasers during their early stages of development.

For medium-haul to long-haul fiber-optic communication applications, one of the main requirements is that the laser transmitter remains single mode under dynamic operation. Using a microwave synthesiser generating a tone at 986 MHz and a power amplifier (27-dBm maximum output power) to excite a step recovery diode (SRD), 36 mA amplitude 100 ps pulses are generated. These are applied to the quasi-single-mode laser that has been prebiased to 60 mA through a bias-tee. Fig. 5 presents the spectrum of the main mode with modulation OFF (dashed) and modulation ON (solid) as measured on a standard single-pass optical spectrum analyzer (OSA) with 0.1 nm resolution. Clearly the laser spectrum has been broadened (chirped) under current modulation, from 0.44 nm to 0.56 nm at 20 dB down from the peak wavelength, subject to the resolution constraints of the OSA. The inset is the spectrum of the laser under modulation over a wider wavelength span and confirms that the device remains single mode under excitation. This confirms that this device type is DSM (dynamic single mode) under current modulation.

### III. CONCLUSION

A modulation bandwidth performance comparable to standard FP lasers, linewidths below 41 MHz and DSM operation have been reported for a quasi-single-mode laser manufactured using a new modal perturbation technique. Further improvements are expected in the quasi-single-mode operating range, the SMSR over this range and consequently the minimum

obtainable linewidth by the introduction of slots at positions  $1/16$  and smaller, of the cavity length. The characteristics of these potentially low-cost quasi-single-mode lasers suggest that these lasers look promising for a range of communication and metrological applications.

### ACKNOWLEDGMENT

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### REFERENCES

- [1] R. K. Willardson and A. C. Beer, "The cleaved coupled cavity laser," W.T. Tsang, in *Semiconductor and Semimetals: Lightwave Communication Technology*, London, U.K.: Academic, 1985, vol. 22B, pp. 257-373.
- [2] P. A. Morton, R. A. Logan, T. Tanbun-Ek, P. F. Sciortino, A. M. Sergeant, R. K. Montgomery, and T. P. Lee, "25 GHz Bandwidth 1.55  $\mu\text{m}$  GaInAsP p-doped strained multiquantum well lasers," *Electron. Lett.*, vol. 28, pp. 2156-2157, 1992.
- [3] M. Okai, M. Suzuki, and T. Taniwatari, "Strained MQW Corrugation-pitched-modulated DFB laser with ultra narrow (3.6 kHz) spectral linewidth," *Electron. Lett.*, vol. 29, pp. 1696-1697, 1993.
- [4] H. Lu, K. W. Leong, M. Cleroux, and N. Puetz, "Singlemode operation over range  $-40$ – $85$   $^{\circ}\text{C}$  in 1.55  $\mu\text{m}$  gain coupled DFB lasers," *Electron. Lett.*, vol. 31, no. 19, pp. 1670-1671, 1995.
- [5] B. Corbett and D. McDonald, "Ridge waveguide single longitudinal mode 1.3  $\mu\text{m}$  Fabry-Perot laser by modal perturbation," *Electron. Lett.*, vol. 31, no. 25, pp. 2181-2182, 1995.
- [6] L. F. DeChiaro, "Spectral width reduction in multi-longitudinal mode lasers by spatial loss profiling," *J. Lightwave Technol.*, vol. 9, no. 8, pp. 975-986, 1991.
- [7] D. A. Kozlowski, J. S. Young, J. M. C. England, and R. G. S. Plumb, "Singlemode 1.3  $\mu\text{m}$  Fabry-Perot lasers by mode suppression," *Electron. Lett.*, vol. 31, no. 8, pp. 648-650, 1995.

